Operative Techniques in
General Surgery

Telerobotic Surgery

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In robotic surgery, all information exchanged between the surgeon and the patient is digitized. This fundamental characteristic of surgical robotics, in concert with a booming telecommunications revolution, has led forward-thinking surgeons to imagine and, in a few cases, make real the practice of telesurgery. On September 7, 2001, Jacques Marescaux and his team from the European Institute of Tele-Surgery (EITS)/Université Louis Pasteur, Strasbourg, France, performed the first transatlantic telerobotic laparoscopic cholecystectomy using the Zeus robot (Computer Motion, Inc., Goleta, CA; now operated by Intuitive Surgical, Inc., Sunnyvale, CA).[1,2] Mehran Anvari has since used this robot to perform advanced laparoscopic surgery from the Centre for Minimal Access Surgery (CMAS)/McMaster University, Hamilton, Ontario, on a number of patients in rural areas of Canada.[3] Although not yet engaged in clinical activity, our United States-based group has recently developed and performed collaborative telerobotic surgery in animals using the advanced, stereoscopic daVinci robot (Intuitive Surgical, Inc., Sunnyvale, CA) and a lower-cost public Internet telecommunications link.[4,5] This article describes and illustrates in detail the: essential programmatic and technical elements of telesurgery; procedural difficulties encountered in telesurgery and the strategies to address such difficulties; probable future applications of telesurgery; and hurdles that need to be overcome to make routine practice of telesurgery a reality.

Evolution from "Conventional" to "Tele" Surgery

The evolution from conventional surgery to robotic telesurgery involved three principle steps, each requiring a paradigm shift for health care providers and patients (Fig. 1). In conventional or "open" surgery, the surgeon is in direct physical contact with the patient. This operative approach provides the surgeon the greatest amount of visual and tactile interaction with the tissue being manipulated. Proponents of conventional surgery argue that wide exposure of the operative field through generous incisions provides easy and safe access to intra-abdominal and intrathoracic organs. Conventional surgery provides surgeons an unobstructed three-dimensional view of the operative field, unhindered ability to feel the tissues, natural dexterity while operating, and the widest possible array of instrumentation. However, the large incisions used in open surgery produce significant inflammation and pain.

In the 1990s, video technology revolutionized surgery by permitting minimally invasive access to the abdominal and thoracic cavities. The greatest advantage of videoscopic surgery is its decrement in invasiveness; thus, reducing the inflammatory response,[6-9] postoperative pain,[10] and convalescence period for patients.[11,12] The obvious disadvantages of minimally invasive surgery for the surgeon include a two-dimensional view of the operative field, reduced haptic feedback from the patient, and reduced dexterity because of limited instrumentation. Patient and surgeon acceptance of minimally invasive surgery forced a paradigm shift that has made telesurgery a practical possibility.[13] Minimally invasive surgery forces the surgeon to visualize the operative field by means of technology and thereby physically disconnects the surgeon from the tissue. At a fundamental level, the interposition of video technology between the surgeon and the patient necessitate that surgeons depend on more than their eyes and hands to operate.[14]

The inherent limitations in vision and dexterity encountered in videoscopic surgery inspired addition of more technology between the surgeon and patient. Surgical robots (described elsewhere in this issue) returned to the surgeon much of what was lost in the transition to minimally invasive surgery. The high fidelity, three-dimensional video system of the daVinci robot produces an incredibly clear, magnified, stereoscopic image that rivals and often exceeds the visualization of tissues encountered in open surgery. Dexterity is also increased in robotic surgery as the instruments have intuitive, articulating "wrists" and the instruments behave similarly (and in some aspects superiorly) to the human hand. While instrumentation is still limited, innovative surgeons and engineers continuously develop additional robotic instruments. There are practical disadvantages to current-generation surgical robots (high costs, long operative times, etc.), and the most significant is that of complete loss of haptic feedback. However, with development of surgical robotic systems (mechanical telemanipulators in which the surgeon console is digitally connected by electronic cables to patient-side manipulators) telesurgery became an eventuality. Tele-

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doi:10.1053/j.optechgensurg.2005.11.002

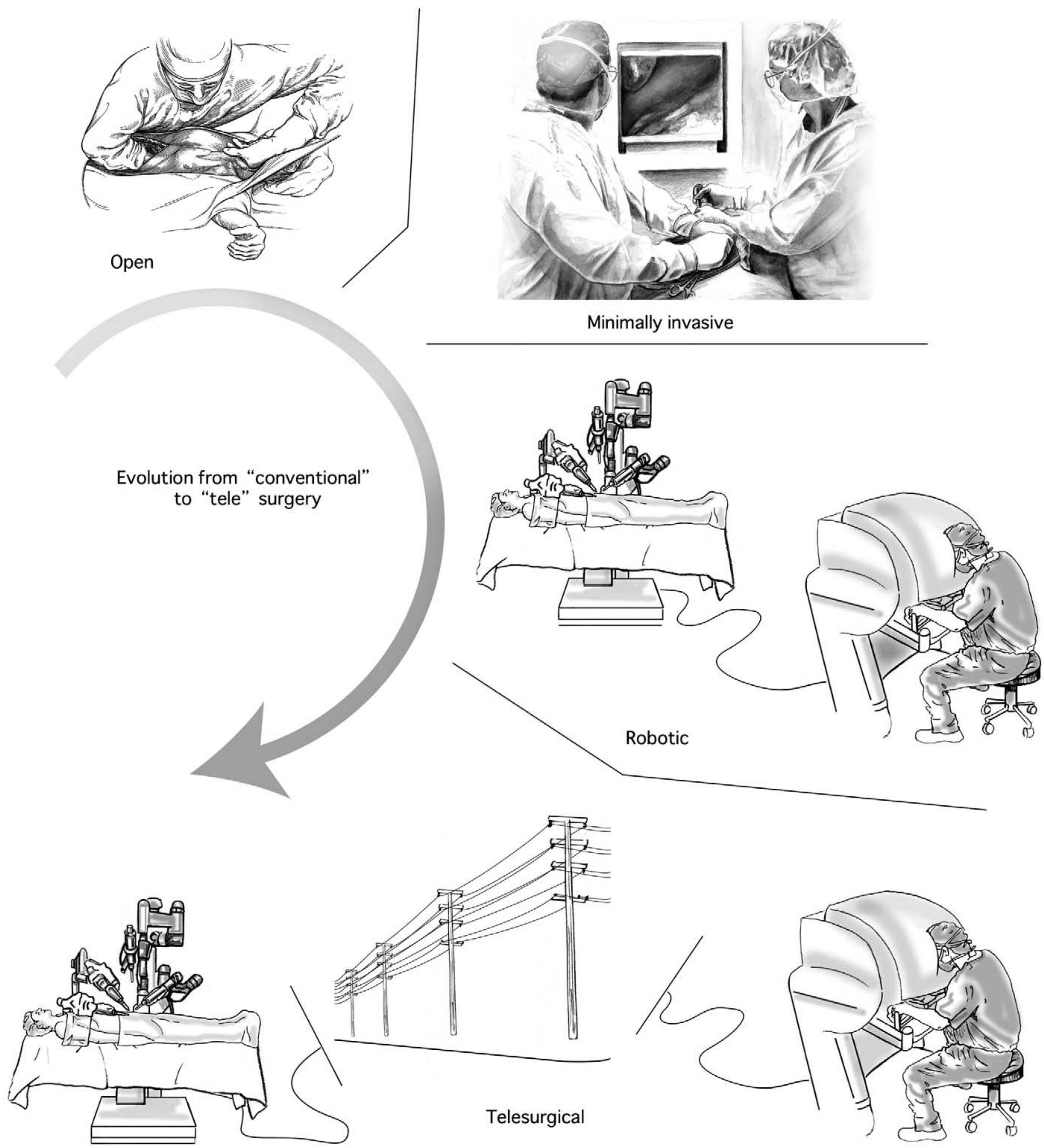

Figure 1 Evolution from "Conventional" to "Tele" surgery.

surgery became a reality when these cables were replaced with more advanced telecommunication technology.

Telerobotic surgery has tremendous potential to provide patients located in rural areas, on the battlefield, at and under the sea, and in extraterrestrial locations,[15] access to expert and subspecialty surgical care. However, as in each of the previous evolutionary steps, telesurgery comes at a cost. Telesurgeons experience decreased visual perception (because of lower bandwidth video), intermittent visual loss (because of data packet loss and/or network congestion), control latency, and visual discrepancy (defined later). Furthermore, telesurgeons still lack haptic feedback from their patients. Although impaired sensory perception makes telerobotic surgery more difficult, our group and others have proven that under the proper conditions telesurgery is safe and effective.[16]

Necessary Elements of a Telerobotic Surgery Team

In its current state, the pieces that make up telesurgery are complex, expensive, and relatively fragmented. To success-

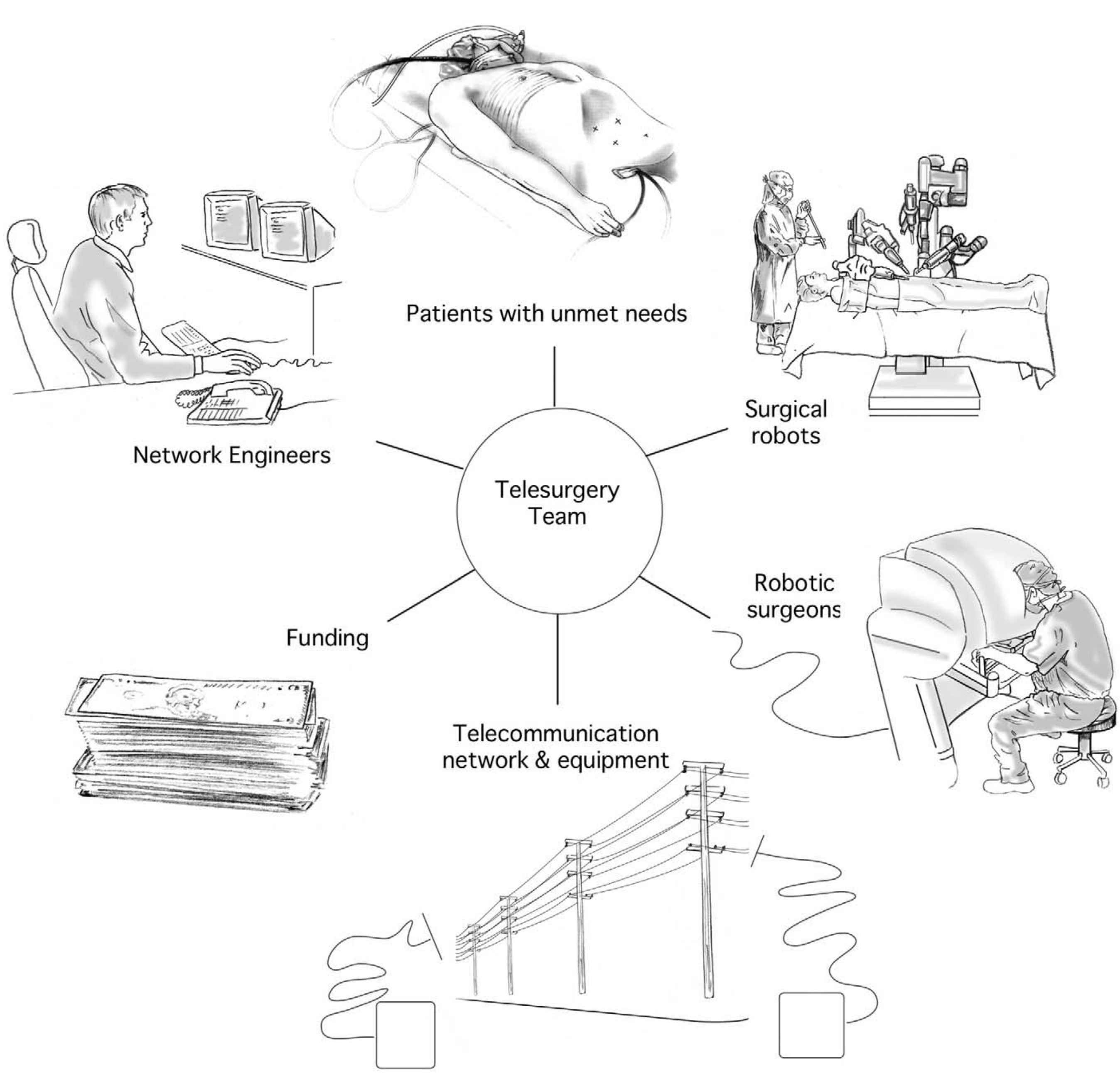

Figure 2 Necessary elements of a telerobotic surgery team.

fully engage in research or clinical care, the telesurgery team must pull together: material resources (surgical robots and telecommunications equipment); surgical and technical expertise (surgeons and engineers with the necessary clinical, robotic and telecommunication skill); clinical motivation and material (clinical need and appropriate patients); and financial support (government, industrial and institutional funding) (Fig. 2).

Previously, two surgical robotic systems were commercially available: the Computer Motion Zeus and Intuitive Surgical daVinci robots. Initially, a single Zeus robot was modified to allow use over a telecommunication network. The merger of Computer Motion and Intuitive Surgical subsequently halted production and support of the Zeus robot. Recently, our group demonstrated the telesurgical capability of a specially configured daVinci robot. Currently, this daVinci represents the only telerobotic surgical system.

Regarding the telecommunications equipment and network used in telesurgery, a number of options are available. Point-to-point connections with guaranteed quality-of-service are the best for telesurgery as they provide very reliable, high bandwidth, and low latency communication. For example, the initial clinical proof-of-concept used a dedicated fiber-optic Asynchronous Transfer Mode (ATM) link to directly connect the surgeon in New York City to the patient in Strasbourg, France. However, such point-to-point connections are expensive and impractical if we extend telesurgical services across a wide geographic area. Use of existing, lower quality-of-service networks both decrease cost and increase accessibility. Unfortunately, lower quality-of-service connections usually result in decreased reliability, overall decrease in visual quality, and increased latency.

Figure 1 illustrates the significant impairment in sensory perception experienced in telesurgery as compared to conventional open, laparoscopic, and even robotic surgery. Not surprisingly, unique combinations of talent and training result in surgeons with different levels of skill in the various types of surgery. Similarly, limited experience has shown that certain surgeons are better telesurgeons than other surgeons. Whether or not a surgeon will make a good telesurgeon appears to depend on their advanced laparoscopic/robotic surgical experience and skill, comfort with telecommunication technology, and ability to compensate for operating with delay. In addition to surgical expertise, successful telerobotic surgery requires robotic support by skilled operating room nurses and manufacturer representatives. Additional technical expertise is required to set up and manage the telecommunications network. Currently, the telecommunication expertise requires a person with skills beyond the skills seen in typical robotic and hospital biomechanical engineering (BME) personnel. Set up and trouble shooting mandates robotic and communication expertise to minimize surgeon and staff frustration. Currently, it is prudent to locate people with robotic and telecommunication expertise at both the surgeon and patient sites. The technical expertise must be robust enough to quickly determine and resolve any application (robot) or network issues.

The projected commercial cost of a telesurgery-capable daVinci robot is predicted to be between \$1.5 and \$2 M. Telesurgery costs also include establishment and use of the telecommunication network as well as support of technical personnel. Eclectic financial support from government, industry, academia, and philanthropy is essential to initiate and sustain a telerobotic surgical program. The high cost of telesurgery also demands that a strong clinical motivation be present for surgeons to engage in the development and practice of this activity. Currently, the greatest motivation for telerobotic surgery comes from the need to provide surgical care to patients who are physically isolated from state-of-the-art medical centers (rural residents of developed nations) and patients who are intentionally placed in extreme environments (such as the battlefield, underwater, and in space).

Essential Components of a Telerobotic Surgery Circuit

The essential components of a telesurgery system are illustrated in Fig. 3. (1) The ideal telecommunications network for telesurgery is both high bandwidth and low latency (later discussed in detail). (2) A telesurgery interface for telerobotic surgery (TITS) which contains video encoder/decoders (CODECs) and other components is needed to connect the robotic surgical system to the telecommunications network. (3) Reliable and clear two-way voice communication between the local and remote sites is essential for the safe practice of telesurgery. This can be achieved using Voice Over Internet Protocol (VOIP) and thus it is possible to integrate audio into the same connection over which visual and robotic control data are transmitted. However, if the telesurgery network connection is limited, it is advisable to use a parallel voice-only connection such as a standard phone line. (4) To improve the situational awareness of the telesurgeon and improve communication between the members of the health care team, two-way videoconferencing greatly enhances the practice of telerobotic surgery. (5) Finally, and perhaps most importantly, the telesurgery circuit requires visualization of the operative field by both local and remote participants. The standard in-room laparoscopic "tower" provides tableside assistants as well as anesthetists, nurses, and technicians a clear picture of the surgical process. After intraoperative video has been processed by the local TITS, transmitted over the network, and reprocessed by the remote TITS, the robotic control console provides the platform for displaying the operative field to the telesurgeon.

Delay in Telerobotic Surgery

The ultimate goal of telerobotic surgery is to replicate the normal process of surgery from a distance. The success of telesurgery (or any aspect of telemedicine for that matter) depends largely on how faithfully and without incident remote activities duplicate their on-site equivalents. Because of its direct impact on surgeon performance, a frequent metric in real-time telesurgery research is that of system delay (Fig. 4).[17]

Control Latency describes the delay in the efferent signal from surgeon to patient. Functionally, control latency represents the time from when a remote surgeon moves a controller to when the surgical tool actually moves inside the patient. Technically, control latency is the sum of delays related to three factors: (1) the time required for the control console to perform mechanoelectric conversion of joystick movements to digital signals, (2) the time required to transmit digital control signals to the patient's location, and (3) electromechanical translation of these signals into movement of robotic surgical instruments.

Visual Discrepancy describes the delay in the afferent signal from patient to surgeon. Functionally, visual discrepancy represents the time from when an object moves in the operative field to when the surgeon sees that movement in the control console. Technically, visual discrepancy results from the sum of delays related to three factors: (1) digitalization and compression of the image from the laparoscopic camera by a video CODEC, (2) transmission of the video signal across a telecommunication network, and (3) decompression of the video signal by the remote CODEC for display in the control console.

Round-Trip Delay describes the total amount of efferent and afferent delay between the surgeon and the patient (the sum of control latency and visual discrepancy). Functionally, round-trip delay represents the time from when a surgeon moves a controller at the remote location to when such movement translated at the patient's location is then visually appreciated by the surgeon at the remote location. Although a number of factors influence the actual time round-trip delay time in telesurgery, the two greatest contributing technical factors are: (1) the efficiency of the CODECs and (2) the speed of transmission across the telecommunications network.

In general, the purpose of a CODEC is to reduce the size of digital video to improve video storage and/or reduce the amount of bandwidth required for video transmission. CODECs are commonly used to reduce the file size of entertainment video. The more the CODEC compresses the video, the shorter it takes to download a particular video over the Internet and the more "special features" that can be included at the end of a DVD. The ultimate goal of all entertainment

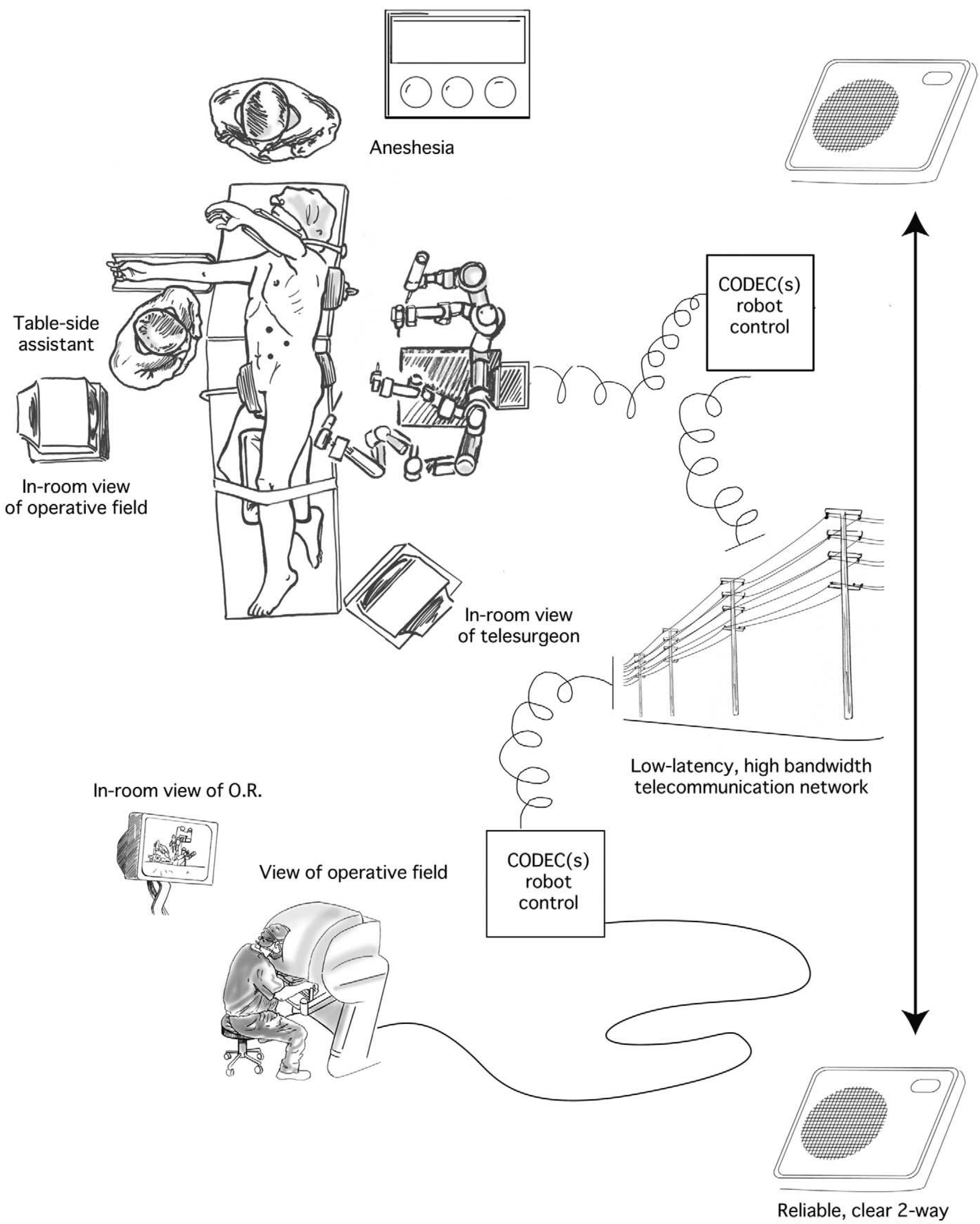

Figure 3 Essential components of a telerobotic surgery circuit.

video CODEC designers is to maintain audio and video quality while further compressing the data. Because standard video is not interactive, the time required for the CODEC to compress or decompress the data are relatively unimportant. The only noticeable effect of a "slow" video CODEC is that it may take a few seconds after you press "play" before your movie starts. However, once the "buffer" is full, the video is seamless.

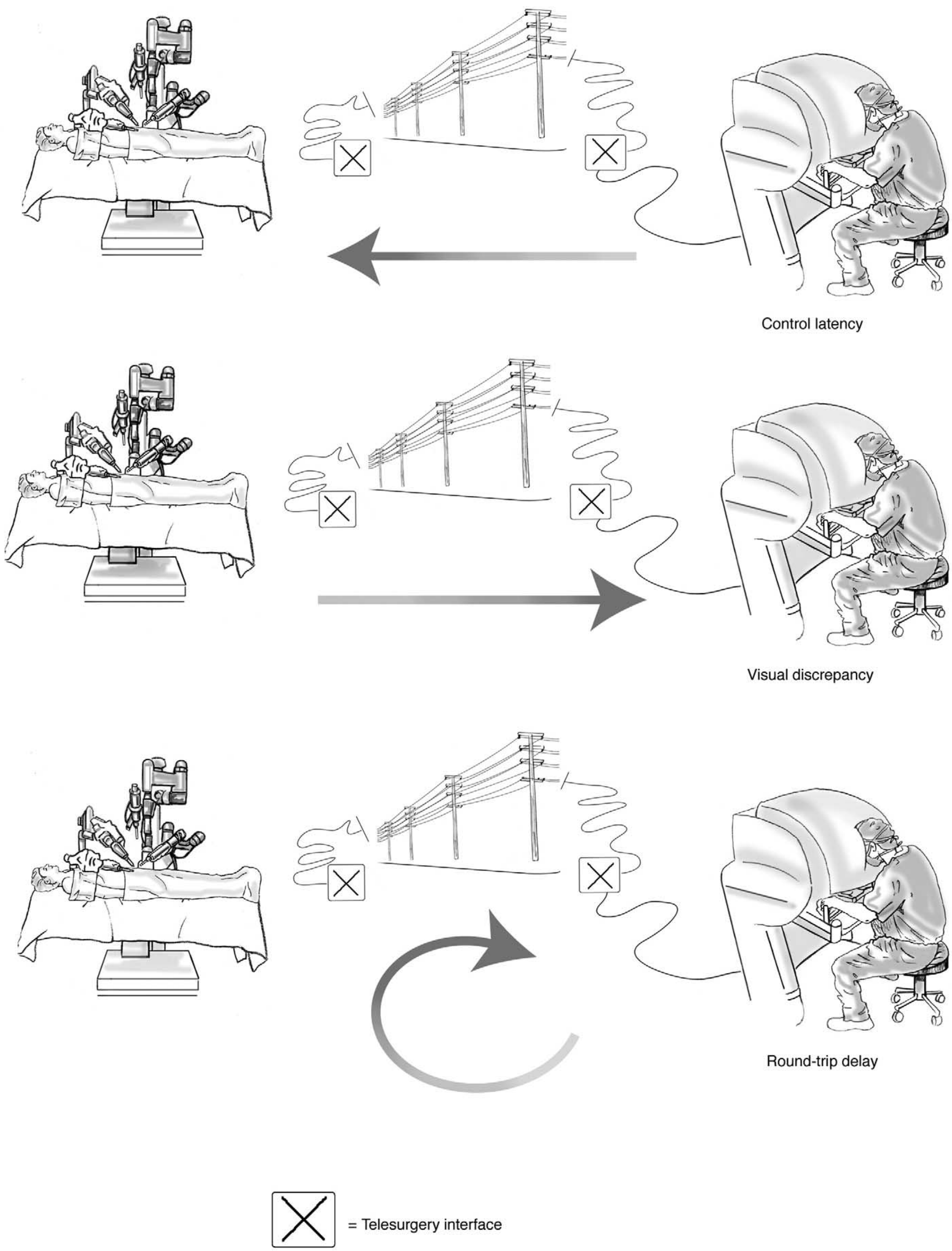

Figure 4 Delay in telerobotic surgery.

CODECs designed for interactive purposes (of which video teleconferencing CODECs are the principle example) need to maintain audio and video quality, but must keep delay within acceptable limits. Anyone who has conversed over a satellite phone knows how disruptive delay can be to the flow of normal conversation. Designers of teleconferencing CODECs understand that customers accept lower quality video images and video delay as long as they are provided adequate quality audio with minimal delay; even though we often notice the movement of the remote persons lips lags behind their voice. In standard configuration, most CODECs prioritize video image quality over latency based on the assumption that a higher quality image is more important than "real time" video.

Because the priorities in telerobotic surgery differ from priorities in video entertainment and teleconferencing, a telesurgery optimized CODEC is greatly needed and represents an active area of research. In telesurgery, the number one priority is the speed and integrity of the mechano-visual loop because this most acutely affects the safety of the patient. Although communication interruptions between operating surgeons are tolerable and poor image quality can be managed, research has shown that the primary determinant of surgeon performance in a telesurgical environment is the amount of round-trip visual feedback delay. Thus, the ideal telesurgery CODEC is one that minimizes visual discrepancy.

The second most important factor influencing the actual round-trip delay time in telesurgery is the effective speed of the telecommunications network. The time required to transfer the telesurgery data over the telecommunications network is primarily affected by three network parameters: transmission distance, bandwidth and quality of service. *Transmission distance* is determined by relative position of the surgeon and patient as well as the network configuration; transmission distance should be minimized as much as practical. *Bandwidth* is a data transmission rate indicating the maximum quantity of information that can be transmitted through a given communications circuit per unit of time. The amount of video, voice, and control data that can be transmitted back-and-forth at a given time is measured in kilobits or megabits per second (kbps or Mbps).[18] Similar to increasing the number of lanes on a congested highway to allow faster flow of traffic, increasing the rate at which data can be transmitted over a network can decrease the time required for the necessary data to be transmitted. *Quality of Service* (QoS) is the degree of guarantee of or commitment to a particular quality of network service (priority) including a defined minimum rate of data delivery (bandwidth) as well as maximum intervals between information packet delivery (latency). Telesurgery, which is particularly sensitive to network delays, is greatly affected by latency.[18] QoS is lowest over the public Internet and is highest with use of dedicated communication assets such as the previously mentioned ATM network used by Marescaux or the relatively well-known Integrated Services Digital Network (ISDN) connection commonly provided by traditional telephone companies. Increasing QoS increases the cost of the telecommunication link. The level of QoS required for government regulatory approval of US clinical telesurgery as well as the QoS required for cost-effective wide spread adoption of telesurgery remain unclear. The dedicated, redundant networks used in initial clinical telesurgery provided high QoS without loss-of-signal during more than 20 operations. Clinical prudence and experience with similar nonmedical telerobotic systems in NASA and the military suggest that loss-of-service protocols should be worked out before embarking on clinical telesurgery. "Fail-safe" clinical use insures patient safety even in the very unlikely event of network failure.

Clinical applications of telesurgery have depended primarily on high-bandwidth, low-latency, high QoS telecommunications services.[1-3] Anvari translated the low population density, presence of isolated rural communities, nationalized health care system, and sophisticated national telecommunications network in Canada into a successful telesurgery service.[16] He has operated on more than 20 patients using a commercial Bell Canada 15 Mbps virtual private network (VPN) connection. Fragmented telecommunication services and high cost limit wide application of a similar telecommunication solution across the United States and Europe. Therefore, our group has focused on lower cost, lower bandwidth applications of telesurgery over the commercial Internet.[19] As previously mentioned, cost-benefit analyses to determine the ideal network configuration for safe widespread clinical use have not yet been performed.

Compensatory Mechanisms for Overcoming Delay

Telesurgery researchers experimenting with different CODECs and networks have investigated the effects of latency on surgical task performance,[20] and have identified a number of strategies that surgeons (consciously or unconsciously) employ to compensate for delay (Fig. 5). Our group has found that, while delays of 500 ms (0.5 seconds) do produce a significant degradation in human task performance, these compensatory mechanisms can be capitalized on to make telesurgery possible even in the 1000 ms (1 second) delay range.[18]

1. Slowing surgeon hand movement greatly reduces the incidence and degree of "overshoot" that often occurs when operating with delay. By making slow, steady movements, the telesurgeon gives the visual image of his instrument time to "catch up" with the actual position of his hand.
2. Telesurgeons learn to anticipate the new location of their instruments. Surgeons create "virtual instruments" that correlate to varying degrees with the actual (rather than visual) position of the instruments. The ability to create an abstract model that accurately reflects the future position of the remote object based on previous controller movement likely represents the mark of a truly talented telesurgeon.
3. When performing telesurgery in a collaborative environment (such as is possible with the experimentally configured daVinci system), the remote (delay-impaired) surgeon generally performs surgical tasks that require relatively less precision (such as retraction, dissection, and mentoring). The local (real-time) surgeon performs the precision-dependant tasks (such as cutting, cautery, and knot tying). Knowledge and skill can

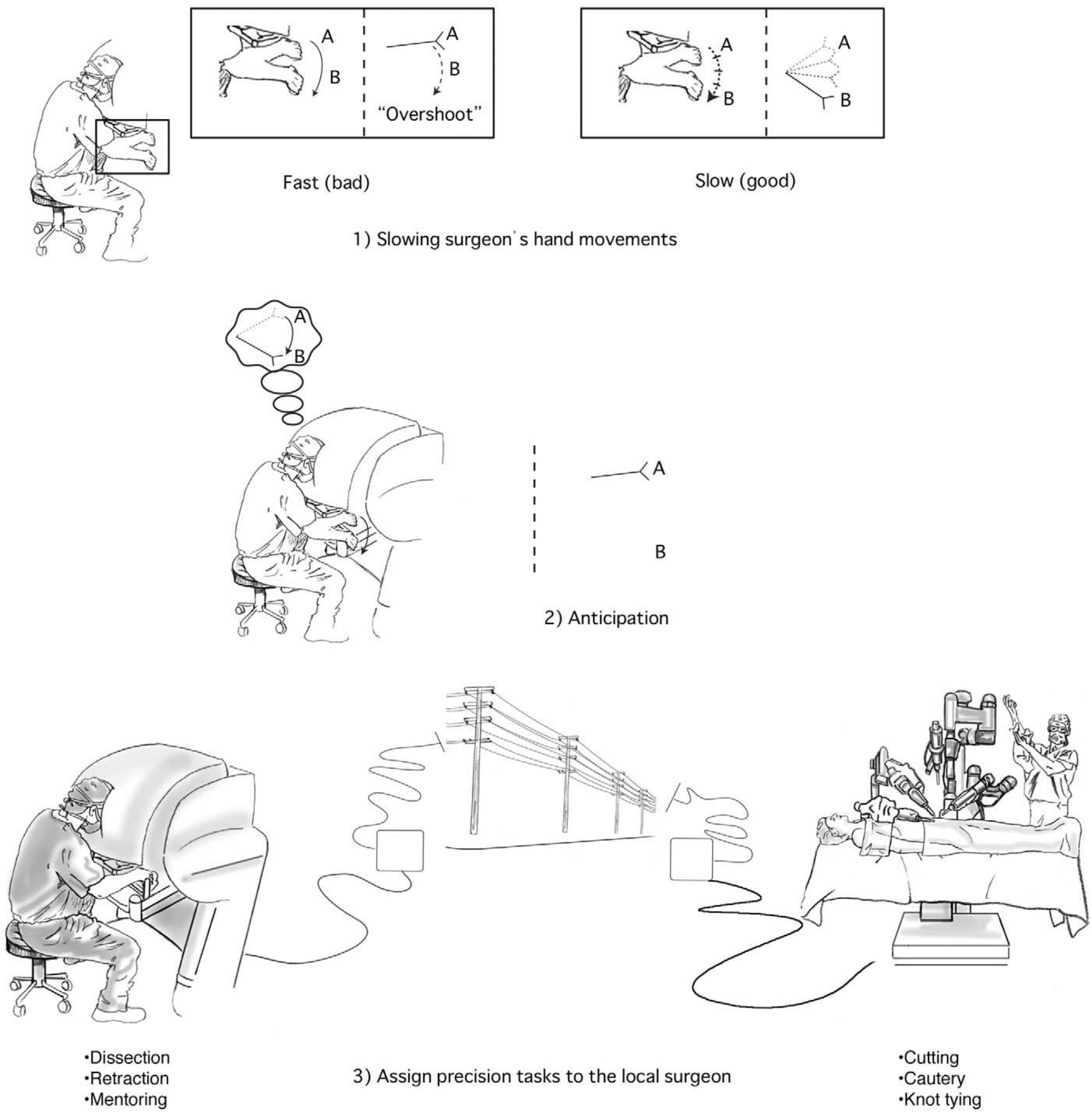

Figure 5 Compensatory mechanisms for overcoming delay.

be translated across distance in this manner despite significant delay.

4. Academic and industrial research indicate that specially designed software and hardware can ameliorate latency in a manner that is similar to the adaptation previously described for the telesurgeon. With regard to stereoscopic telesurgery, the use of a video synchronizer which delays one channel by up to a frame to allow a delayed frame from the other channel to "catch up" eliminates the severe degradation in performance experienced with intraocular discrepancy.[21]

Additionally, repetitive movement within the operative field (such as occurs with respiration, cardiac contraction, and vessel pulsation) can make the location of the tissues difficult to ascertain when operating with delay. Simple techniques such as ventilator management can help with this problem in the short term and computer-assisted gated movement promises to eliminate this problem in long term. Finally, by scheduling telesurgical cases during times when the Internet is not busy, the telesurgeon can improve the quality of the Internet connection and thereby reduce the latency that must be overcome.

Telesurgery has the potential to connect expert and subspecialist surgeons to patients located in isolated areas where access to major medical centers and/or specialty care is difficult to achieve (Fig. 6). Providing surgeons the ability to mentor and perform procedures from remote locations will, in the future, have a profound impact on the

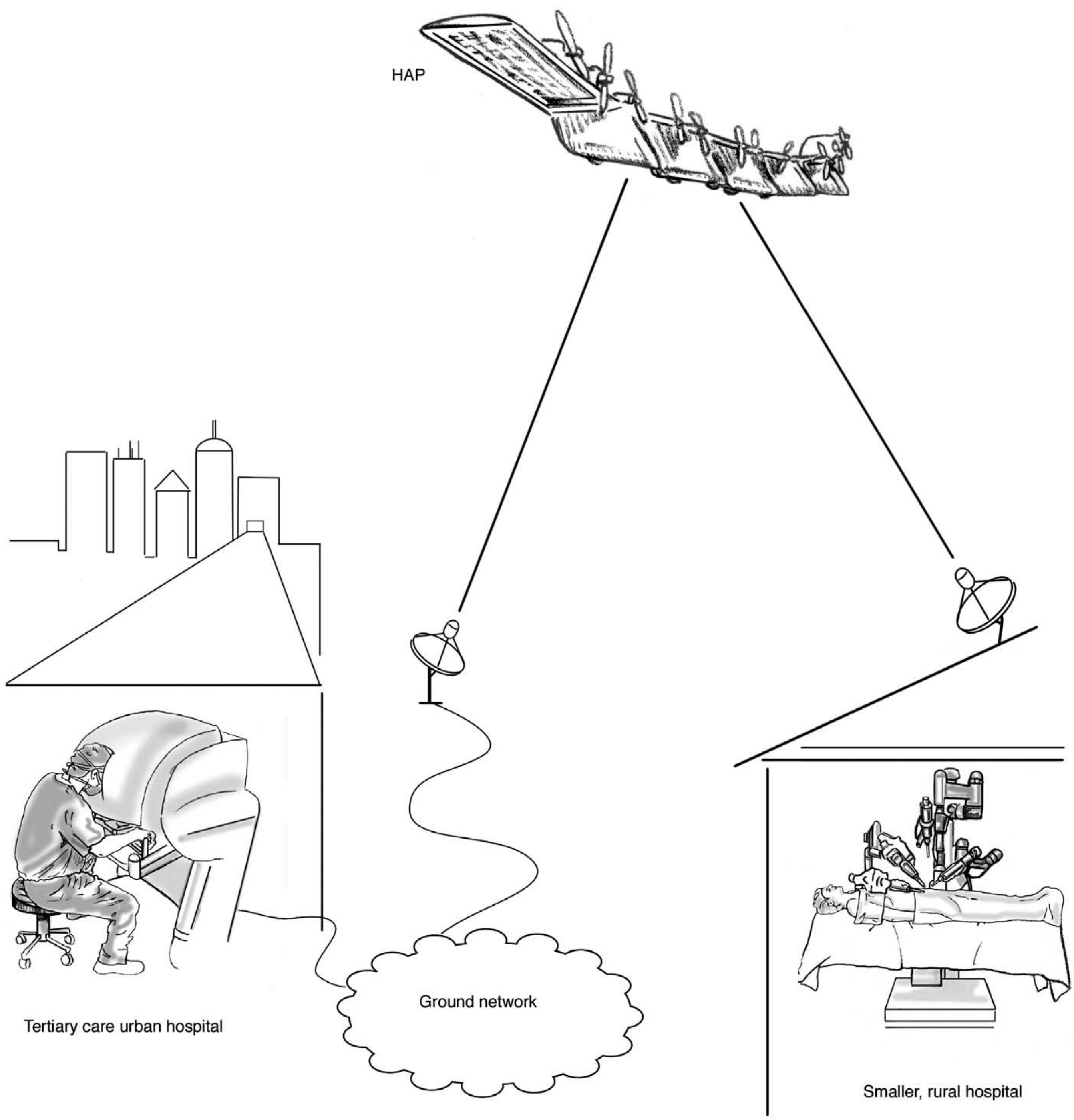

Figure 6 Telesurgery has the potential to connect expert and subspecialist surgeons to patients located in isolated areas where access to major medical centers and/or specialty care is difficult to achieve.

quality and type of care available to patients in rural settings as well as patients in extreme and remote environments such as the battlefield, at and under the sea, and in extraterrestrial locations.[15]

As telesurgery gains acceptance within the surgical community, we envision networks of telesurgeons operating on patients located in both remote mobile and fixed telesurgery suites. Widespread application necessitates cooperation of multiple telecommunication providers; network issues increase with the addition of every network provider and interfaces. Unfortunately, the QoS provided by the entire network is only as good as the QoS on the worst leg of the network. Providing telesurgery to underserved rural patients is currently difficult as the final leg or "last mile" is in general insufficient.

Novel wireless communication technology shows promise in the rural application of telesurgery. Because the delay associated with satellite communication is significant, we continue to explore mobile robotic telesurgery using alternative technologies such as high altitude unmanned airborne vehicle communication systems. For example, Helios (AeroVironment, Inc., Monrovia, CA) is a prototype lightweight solar-electric flying wing that could provide broadband, low latency telecommunication to rural communities that would be ideal for use in telesurgery.

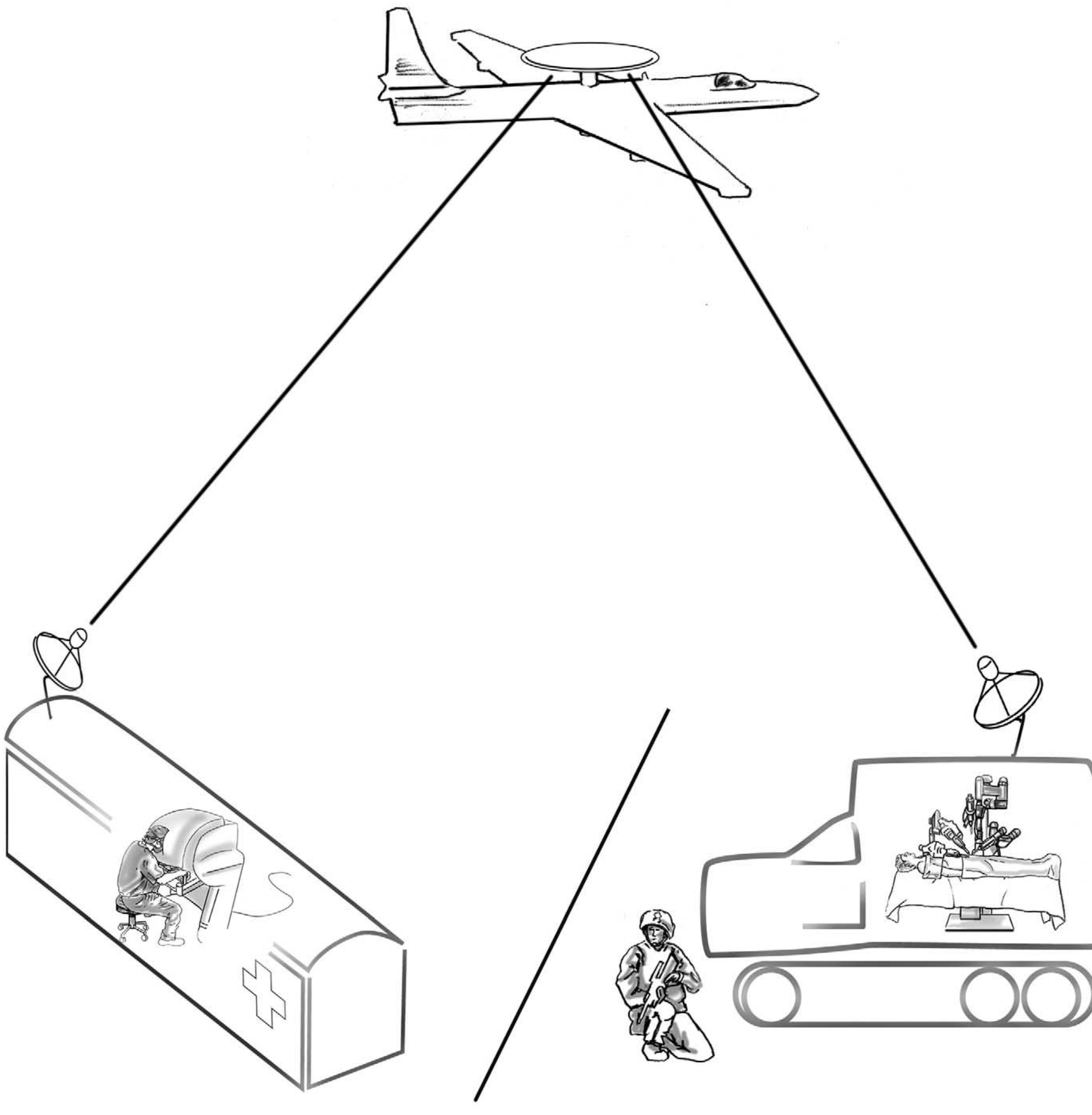

Figure 7 Battlefield telerobotic surgery.

Battlefield Telerobotic Surgery

The future application of telesurgery for patients in extreme environments is currently providing the bulk of the funding for the development of telesurgery (Fig. 7). It is often time and cost prohibitive to evacuate soldiers, mariners, submariners, and astronauts from their extreme environments to undergo urgent or emergent surgery.[22,23] The mortality rate for injured American armed service members during Operations Enduring Freedom (OEF) and Iraqi Freedom (OIF) (10%) was decreased by 67% compared to the mortality rate for soldiers injured in World War II (30%), and by 58% compared with the mortality rate during Operation Desert Storm (24%).[24] The decrease in mortality rate has occurred despite an increase in the severity and complexity of wounds suffered. While the significant increase in survival is in part because of improved medical care, it is primarily the result of the decrease in time required to receive definitive medical care. The majority of modern war deaths occur within the first hour after injury; the "golden hour." Limited medical assets and unacceptably high human risk suggest we will not be able to address this unmet medical need by placing multiple surgical teams across the front lines of battle. A force multiplying and asset protecting surgical solution is to deliver immediate definitive surgical care to wounded soldiers throughout the battlefield via telerobotic surgery.

The DARPA (Defense Advanced Research Projects Agency) Trauma Pod project is targeted to develop an autonomous robotic system that will deliver life-saving telerobotic casualty care to injured soldiers on the battlefield. Although this system replaces the circulating and scrub nurse with autonomous robots, the surgeon will provide expert care at a distance through a remotely operated surgical robot.[25] Similar to future pilots remotely flying the Unmanned Combat Air Vehicle, future military surgeons could remotely perform life-saving surgery on soldiers moments after their injury.

Current Barriers and Limitations

While it is clear that surgical robotics will have a significant impact on the way we practice surgery (even with respect to aspects of surgery as fundamental as the doctor-patient relationship) a number of technical, economic, legal, and social factors currently prevent widespread adoption of telesurgery.

One of the most frustrating problems surgeons run into when developing a telesurgery program is network firewalls. For example, firewalls routinely separate academic and clinical computing networks within academic medical centers. University computer security and health care HIPAA (Health Insurance Portability and Accountability Act) concerns divide academic and health care networks despite close physical proximity. Creative hardware and software solutions allow passage of telesurgical data across firewalls with minimal delay. For example, network administrators may open certain ports, monitor them during telerobotic surgery use, and then immediately turn them off when the procedure is complete. Network configuration and encryption readily address security issues and HIPAA compliance without introducing inordinate amounts of telecommunication delay.

Electromagnetic interference (EMI) can be problematic when introducing nonmedical telecommunications equipment into an environment filled with diagnostic and therapeutic medical equipment. Telesurgeons must ensure that all equipment brought into an operating room is in compliance with federal regulations. Again, creative solutions are often required for successful implementation. For example, wrapping telecommunication equipment in a lead X-ray gown or aluminum foil can shield the equipment enough to allow successful telesurgery.

In addition to the significant cost of purchasing and maintaining a surgical robot, many smaller rural hospitals do not have the telecommunications infrastructure to support telesurgery (primarily a bandwidth constraint). The cost of outfitting multiple appropriate target hospitals with a surgical robot and network suitable for telesurgery is currently too high for widespread adoption. Similar to current mobile magnetic resonance imaging (MRI) scanners, mobile telesurgery solutions that serve many different rural locations may provide a more cost-effective solution.

Legal issues in the United States associated with credentialing, licensing, and reimbursement have not yet been worked out, but are being explored. For example, the Office for the Advancement of Telehealth (OAT) plans to fund grants that will remove technical, legal and regulatory barriers to the deployment of telehealth technologies as well as grants to state health licensing boards to develop cooperative polices that reduce regulatory barriers to telehealth. The future success of telerobotic surgery depends a great deal on such initiatives. The FDA continues to evolve with regards to regulation and approval of digital medical devices.

Finally, the question of whether or not society is ready for the routine practice of telesurgery remains unanswered. Are patients willing to put their lives in the hands of surgeons they've only met over the phone? An ever more technologically dependent society that increasingly incorporates telecommunication into our daily lives may be inadvertently preparing patients for telesurgery. In fact, many patients now routinely obtain second opinions from physicians they have only met on the telephone or Internet. While it is unclear if patients and surgeons will embrace the paradigm shift that telesurgery represents, the initial clinical experience across the world suggest that surgeons and patients readily embrace telesurgery when it is circumspectly applied.

Clinical Issues

Because the current surgical robot was designed for use in minimally invasive surgery, many of the clinical issues which affect laparoscopy and robotic surgery also affect telerobotic surgery. While port placement is obviously important in laparoscopy, port placement is even more important in robotic-assisted laparoscopic surgery as poor port placement can result in robot arm collisions that make an operation very difficult if not impossible. Optimal placement of the robotic ports is equally important in telerobotic surgery. As the local surgeon is less experienced than the remote surgeon, optimally placing the ports is even more difficult in a telesurgical environment. Collaboration of local and remote surgeons in robotic telesurgery begins *before* the first incision is made as proper positioning of the patient, robot and ports is crucial for successful outcome. As is the case with conventional robotic surgery, the placement of an additional nonrobotic laparoscopic port for use by the assistant is particularly helpful. The assistant can then suction, apply clips, and staple with minimal disruption of operative flow. Preoperatively, the surgeon should clearly define an operative plan and schedule. Failure to progress or the development of a complication should be quickly addressed by conversion to laparoscopic or open surgery and the remote surgeon should be relegated to the role of telementor. Use of as skilled a local surgeon as possible will reduce the frequency and magnitude of complications.

Patient Selection

Inanimate and animate experiments that validate use of the specific robot and network configuration are required before clinical use. These experiments should provide sufficient data to convince the patient, surgeon and Institutional Review Board (IRB) that clinical use is appropriate. The clinical research protocol should target patients and procedures that maximize the likelihood of success. Straightforward patients (thin, healthy patients without prior abdominal surgery) should be offered straightforward procedures (elective, low-risk procedures) in the initial experience. As previously mentioned, French and Canadian patients have been very happy to participate in the telesurgery clinical trials. In general, patient acceptance of robotic telesurgery appears similar to patient acceptance of conventional robotic surgery.

Conclusions

While telesurgery is in its infancy, the advances in video, robotic, and telecommunications technology made over the past 25 years have paved the way for this exciting new field. The ability to capture, compress, enhance, and transmit digital video, voice, and end-effector control data over long distances has made telesurgery a reality. Computer-assisted telemanipulators and advanced telecommunication technology represent the surgical tools of the modern telesurgeon.

Telerobotic surgery is an exciting new discipline that promises to broaden the scope and practice of expert surgeons.[26] As researchers decrease the network requirements for telesurgery, adapt advanced telecommunication networks for telesurgical use, and train surgeons to safely and effectively operate in an environment of mechanical and visual-feedback delay, extreme environments such as the battlefield will no longer be places where patients are isolated from needed surgical care. As technical, social, political, and economic barriers to routine telesurgery are overcome, telesurgery networks will connect rural patients with expert subspecialty surgical care.

Even now, surgery is being performed over great distances to bring expert surgical care to physically isolated patients with otherwise limited health care access. Just as the Internet has revolutionized the way consumers shop, telesurgery may similarly transform surgical care. In the future, patients may stay in their local hospitals and simply "dial-up" the best telesurgeon for their specific operation. Telesurgery will play an increasingly important role in the modern delivery of surgical care over the ensuing decades.

Acknowledgments

Supported in part by the Telemedicine and Advanced Technology Research Center, United States Army Medical Research and Materiel Command, Fort Detrick, MD.

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